Journal of Stored Products Research 73 (2017) 54–61

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

Efficacy of alpha-cypermethrin, chlorfenapyr and pirimiphos-methyl applied on polypropylene bags for the control of *Prostephanus truncatus* (Horn), *Rhyzopertha dominica* (F.) and *Sitophilus oryzae* (L.)

Nickolas G. Kavallieratos [a,*], Christos G. Athanassiou [b], Erifili P. Nika [a], Maria C. Boukouvala [a,c]

[a] *Laboratory of Agricultural Zoology and Entomology, Department of Crop Science, Agricultural University of Athens, 75 Iera Odos str., 11855, Athens, Attica, Greece*

[b] *Laboratory of Entomology and Agricultural Zoology, Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Phytokou str., Nea Ionia, 38446, Magnissia, Greece*

[c] *Laboratory of Organic Chemistry, Department of Chemistry, University of Ioannina, Panepistimioupolis, 45110, Ioannina, Greece*

A R T I C L E I N F O

Article history:
Received 5 May 2017
Received in revised form
10 June 2017
Accepted 23 June 2017
Available online 13 July 2017

Keywords:
Storage bags
Alpha-cypermethrin
Chlorfenapyr
Pirimiphos-methyl
Stored-product insects
Polypropylene

A B S T R A C T

We examined the immediate and delayed mortality of adults of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrychidae), the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) and the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) on surfaces of polypropylene storage bags under different treatment scenarios with alpha-cypermethrin, chlorfenapyr and pirimiphos-methyl. These scenarios were: only one surface of the bag was sprayed and insects were exposed on sprayed or unsprayed surface or both surfaces were sprayed. We evaluated the immediate mortality for 1, 3 and 5 days (d) of exposure. Then, we transferred the surviving adults to untreated surfaces of the same type of storage bags and measured the delayed mortality after 7 d of exposure. We also evaluated the effect of insecticidal treatments on the numbers of holes/bites made by the activity of *P. truncatus* and *R. dominica* on storage bags. In terms of immediate mortality, chlorfenapyr and pirimiphos-methyl were very effective against all three species and alpha-cypermethrin against *P. truncatus*. We noticed high mortality values of all species to chlorfenapyr and pirimiphos-methyl, even after 3 d of exposure, reaching 100% in many of the cases examined. For the majority of exposure intervals, insecticides and insects, we did not find significant differences in mortality counts between exposures on sprayed surfaces of the bag. Immediate mortalities of insects exposed on the untreated surface of the bag did not differ significantly with mortalities at the surface single treated with alpha-cypermethrin and pirimiphos-methyl. Concerning delayed mortality, all *S. oryzae* adults were found dead 7 d after their transfer to untreated bags irrespectively of the treatment. The delayed mortality of *P. truncatus* and *R. dominica* adults was either complete (after exposure to chlorfenapyr) or almost complete (after exposure to alpha-cypermethrin). The exposure of *P. truncatus* and *R. dominica* to alpha-cypermethrin almost completely suppressed the numbers of holes/bites. Our study indicates that the application of insecticides on polypropylene storage bags can be considered as an effective method for the control of stored-product insects.

1. Introduction

Storage of grains in bags is a common technique at local or national levels that facilitate international trade and pest management in developing countries but also worldwide (Gahukar, 1994; Mullen et al., 2012; Kavallieratos et al., 2017). The most common materials, among over 30 different types, that are used for the construction of storage bags are paper and plastic (i.e., polyester, polyethylene, polypropylene) (Athanassiou et al., 2011; Mullen et al., 2012; Stejskal et al., 2017). These materials are subjected to different levels of insect penetration or invasion depending not only on their chemical structure, the number of

* Corresponding author.
E-mail address: nick_kaval@hotmail.com (N.G. Kavallieratos).

http://dx.doi.org/10.1016/j.jspr.2017.06.005
0022-474X/

layers they consist of and possible defects of sealing but also on the species of the attacking insects and whether they attack the printed or unprinted surface (Riudavets et al., 2007; Athanassiou et al., 2011; Stejskal et al., 2017). Given that insects cause considerable losses of agricultural commodities during their storage and transportation (Hill, 2003; Mason and McDonough, 2012), they can open holes onto packaging materials (penetrators) or pass through already existing holes (invaders) (Highland, 1984, 1991) and that packaging process is very expensive (Mullen et al., 2012), effective management strategies should be established to substantially reduce or eliminate the insect-infestations when products are stored inside bags. For that purpose, improvement of the packaging material has been recommended, such as the introduction of metals in packaging materials (e.g., metalized polypropylene), development of multilayer packaging (e.g., paper, polyethylene, aluminium and polyethylene), enhancing sealing, reducing the diameter of existing holes in packages or blocking product odors that leave package (Mullen, 1994, 1997; Mullen and Mowery, 2000; Riudavets et al., 2007; Athanassiou et al., 2011; Mullen et al., 2012; Stejskal et al., 2017).

One other possible solution is the treatment of storage bags with registered insecticides. This concept started coming into consideration in mid '80s when Highland and Cline (1986) applied the pyrethroid permethrin on plastic packaging materials against several stored-product insects. Much later, Kim et al. (2013) incorporated plant oil and polysaccharide or plant oil and synthetic polymer and reported good efficacy for the control of the Indian meal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae). In a recent study, Scheff et al. (2016) treated polyethylene-to-polyethylene (PE-PE) and polyethylene terephthalate-to-polyethylene (PET-PE) with the juvenile hormone analogue methoprene and examined several biological parameters of the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) and the warehouse beetle, *Trogoderma variabile* (Ballion) (Coleoptera: Dermestidae). The authors found that no eggs reached the adult stage on methoprene-treated PE-PE or PET-PE while the emergence of eggs to adults was reduced at a range from 87 to 97%. In a most recent study, Kavallieratos et al. (2017) exposed adults of seven stored-product species on the ZeroFly® polypropylene polymer storage bags (Vestergaard S.A., Lausanne, Switzerland) that had been impregnated with the pyrethroid deltamethrin and found that after 5 d of exposure all adults of the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) were dead, while all adults of *T. variabile*, the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrychidae), the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) or *T. castaneum* were immobilized after 1 h of exposure. Similarly, the ZeroFly® bags provided adequate protection against *Cryptolestes* spp., *Sitophilus* spp. and *Tribolium* spp. for a 4-months storage period (Paudyal et al., 2017). The incorporation of deltamethrin to these tested bags follows similar technique to impregnated bed nets (PermaNet® 2.0) against mosquitoes that are manufactured by the same industry (Kavallieratos et al., 2017).

Although bed nets have been infused with different active ingredients, i.e., cypermethrin, deltamethrin, metofluthrin, boric acid, for the control of different blood-sucking dipterans (Martins Campos et al., 2012; Mondal et al., 2016; Ponlawat et al., 2016; Saghafipour et al., 2016), no similar method has been adapted for storage bags. There are no published data evaluating the efficacy of alpha-cypermethrin, chlorfenapyr and pirimiphos-methyl applied on storage bags against *P. truncatus*, *R. dominica* and *S. oryzae*, all classified as penetrators of packaged products (Navarro, 2012; Kavallieratos et al., 2017). Therefore, the objective of the present study was to estimate immediate and delayed mortality of these species on storage bags treated with three insecticides, alpha-cypermethrin, chlorfenapyr and pirimiphos-methyl, that have different modes of action under different treatment scenarios. The effect of insecticidal treatments on the numbers of holes/bites made by the activity of *P. truncatus* and *R. dominica* on storage bags was also examined.

2. Materials and methods

2.1. Insects

The three tested species were adults of *P. truncatus*, *R. dominica* and *S. oryzae*. *Prostephanus truncatus* colonies were started in 2003 while *R. dominica* and *S. oryzae* colonies, initially collected from Greek storage facilities, were established in 2002. All cultures are currently maintained at the Laboratory of Agricultural Zoology and Entomology, Agricultural University of Athens. *Prostephanus truncatus* was cultured on whole maize at 30 °C, 65% r.h. and continuous darkness. *Rhyzopertha dominica* and *S. oryzae* were cultured on whole wheat at 25 °C, 65% relative humidity (r.h.) and continuous darkness.

2.2. Formulations

The following insecticidal formulations were tested in the present study: Power SC with 62.4 g/l alpha-cypermethrin active ingredient (a.i.) (provided by Hybrid Hellas, Metamorphossis, Greece), Phantom EC with 21.45% chlorfenapyr (a.i.) (provided by BASF Hellas, Amaroussion, Greece) and Actellic EC with 50% pirimiphos-methyl (a.i.) (provided by Syngenta, Anthousa, Greece).

2.3. Bioassays

Woven polypropylene bags (Hatzigeorgiou - Fakaros G.P., Aigaleo, Greece) that were manufactured for olives, cotton, charcoal, wood and storage of grains were used in the tests. The bags have thickness of 100 μm (measured with a No 208M Starret micrometer, Athol, MA, USA), strength of warp minimum 44.3 kgf, strength of weft minimum 40.2 kgf, weaving 10×9 threads per inch, density of warp 10 threads per inch and density of weft 9 threads per inch. The formulations were tested at the label doses for surface treatments. Therefore, alpha-cypermethrin, chlorfenapyr and pirimiphos-methyl were tested at 0.10 mg (a.i.)/cm^2, 0.11 mg (a.i.)/cm^2 and 0.05 mg (a.i.)/cm^2, respectively. The tests were conducted in a completely randomized block design, with three subreplicates and three replicates in glass petri dishes (8 cm diameter by 1.5 cm high) that have a surface area of 50.27 cm^2. The bottoms of the dishes were covered with bags that were cut in a circular shape. The circular pieces of bags were sprayed with 1 ml of an aqueous solution, as a fine mist, which contained the appropriate volume of alpha-cypermethrin, chlorfenapyr or pirimiphos-methyl corresponding to each dose. Spraying was conducted using an AG-4 airbrush (Mecafer S.A., Valence, France) as follows: a) only one surface was sprayed, b) both surfaces were sprayed. The sprayed items were left to dry for 24 h (h) at 30 °C and 65% r.h. Then, the bags with both treated surfaces were affixed to the bottom of the dishes while the bags with only one surface treated were affixed to the bottom of the dishes, having the treated surface either facing up or facing down, and then sealed with white adhesive sealant (Zwaluw Star Acryl, Den Braven, Oosterhout, The Netherlands) by using a bead of this material placed only along the border of the bag and the dish. An additional series of dishes were prepared and sprayed with distilled water as described above and served as controls. The internal sides of the dishes were coated by polytetrafluoroethylen (60 wt % dispersion in water) (Sigma-Aldrich Chemie GmbH, Taufkirchen, Germany), to prevent escape of the